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Motional Dynamics of Coupled Pontoons in Seaways

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ABSTRACT

The United States Navy is developing the connecting technology required to assemble floating platforms under conditions of elevated sea states, using ISO-configured pontoons suitable for rapid transport aboard commercial containerships. Assembly of pontoon structures on open water is influenced substantially by rapid, random motions induced by waves, requiring a means for drawing together and aligning adjoining pontoons as the connection is made. The sea keeping characteristics of pontoons that are coupled both mechanically and hydrodynamically have been established to guide the design of connecting hardware. Hydraulic model tests conducted by the Naval Facilities Engineering Service Center (NFESC) indicate that a particular coupling apparatus may either reduce or augment wave-induced relative motion, depending on the layout and dynamic characteristics of the rigging system. Improper rigging could result in unacceptable excursions between sections - relative motions leading to collisions between pontoons or over tensioning of drawing lines - both problems that limit the success of engaging the coupling apparatus. The dynamic behavior of coupled pontoon sections is most sensitive to the level of pre-tensioning measured within the drawing lines. This paper presents the motional characteristics of a pair of coupled, ISO-configured pontoons as observed in a hydraulic model test, and addresses the significance of these tests to the design of rigid connectors.

KEYWORDS: ISO-configured**,** pontoons, modular construction, at-sea assembly, progressive connection, separation distance, dynamic motions, hydrodynamic and mechanical couplings.

INTRODUCTION

Pontoon-based platforms are used widely in both inland and offshore waters. Their simple construction and large payload capacity provide reliable working surfaces at a low cost. However, current Navy pontoons are not easily relocated by available sealift vessels due to their large size and blunt hull shape, and hence, are limited in their service watch circle. Modular construction techniques that allow on-site assembly from small components is one design approach to achieve the desired mobility. The Navy has proposed a general method of pontoon assembly based on logistical requirements, seaway performance criteria, and existing shipping technology. The current vision of this assembly method sees basic building blocks measuring (nominally) 12.2 m in length, 7.3 m in width, and 2.4 m in depth, dimensions equivalent to the size of three 12.2-meter long International Organization for Standardization (ISO) containers joined laterally (Kane 1996). Regardless of the particular pontoon configuration, the entire system is driven by the on-site assembly technology.

Perhaps the greatest technical challenge to assembly at sea results from the random nature of seaways. Coupling devices must accommodate the relative motions between adjoining pontoons. The study completed by NFESC concludes that at-sea assembly can be accomplished by joining the pontoons progressively. Specifically, in the progressive connection, neighboring pontoons are drawn from an initial separation distance and aligned under increasing control so that relative motions are dampened gradually to amplitudes small enough to safely engage the connector components. Features required in this approach include: a rigging method to bring modules together, a bumper system to prevent collision damage, an alignment guide to initiate mating, and a permanent load bearing mechanism. The operational scenario, critical functional mechanisms, and structural layout of the basic concept are outlined in **(**Huang 1995 and 1996a). Recent updates of the technology are discussed in the text that follows.

SUMMARY OF THE RIGID CONNECTION SYSTEM

Developing the proposed rigid connection system has expanded substantially during the past year as a result of successful hydraulic model tests conducted in 1995 (Huang, 1996a). Figures 1 to 3 illustrate one application of the progressive connection concept. This particular example represents an essentially hazard free system that requires little logistic support. The connection system performs adequately in rough waters exceeding a sea state 3 condition, using two tugs with a 22.2 KN (5,000 lbs) bollard pull, at least one of which is also equipped with a winch of 66.7 KN (15,000 pound) capacity. One person on each pontoon, in addition to the tug crews, is required to connect rigging lines and trigger the final locking mechanism of the connection system. Figure 1 shows the general layout of the connection system, including four rigid connector assemblies (two at each end of the two mating pontoons), a pair of alignment pins, and marriage-bridle rigging that is attached to the end of each alignment pin. The other end of the bridle is attached to the winch on one of the tugs as shown in Figure 2. Figure 3 illustrates the structural details of the rigid connector assembly, consisting of a spring loaded stabbing pin, receptacle, roller racks, built-in crow bars, and restraining guillotines, which all fit into a steel frame. Actual layouts can vary to fit specific pontoon geometry and operational requirements. The inboard end of the stabbing pin bears against a spring support contained in a canister, which is mounted on rollers so that the pin and canister assembly can slide forward and backward in the ready and stowed modes, respectively. The pin and recoil canister at full extension are held at the inboard end. Further retraction of the stab pin as a result of pontoon collision passes the impact energy to the recoil spring. When a pin is properly engaged within its receptacle, a guillotine locking collar within a vertical guide channel drops from the deck to capture the recessed groove near the outboard end of the stabbing pin. The guillotine then bears against the guide channel preventing the pin from slipping out.

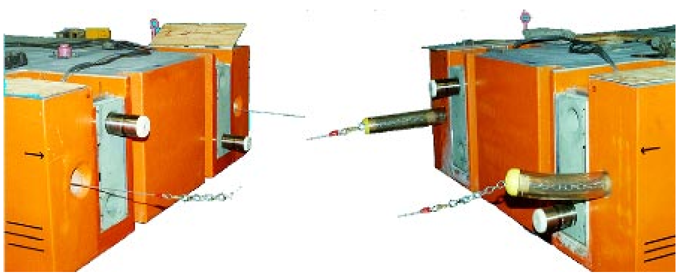


Figure 1. Connector System.

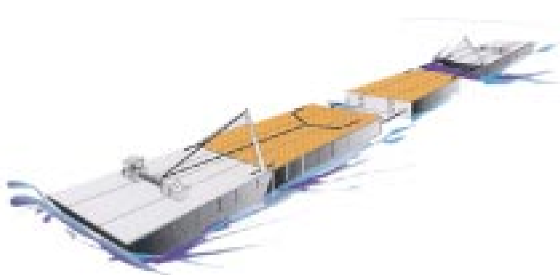


Figure 2. Baseline Concept.

Figure 3 Rigid connector assembly

Figure 3. Rigid Connector Assembly.

The alignment pin is simply a section of chain covered by an elastomeric sleeve. However, it performs the critical function of intermediate transition effectively, as experiments have shown. The combination of chain and sleeve is flexible enough to accommodate wild differential motions, yet sufficiently robust to withstand vigorous dynamic loads. Chains outperform rods or wire ropes as tendons because of strength and flexibility properties, and ability to absorb shock loads. The elastomeric sleeve prevents direct steel-to-steel abrasion and keeps the chain from tangling. The sleeve allows for substantial bending, yet is effective in restraining the differential translations between pontoons at short free lengths due to a relatively large cross section. Alignment pins are able to closely synchronize the random differential motions at the connection interface without suffering debilitating damage, and maintain the stabbing pins within close proximity to their respective receptacles long enough for connectors to engage.

The connection process begins the moment that pontoons are launched from the delivery ship. Tugs assume control of pontoons at ship side and tow them to an open site for connection. A pair of tugs and pontoons is aligned at a separation distance of roughly 12 m. With the spring-loaded stab pins extended, messenger lines carrying the split-leg bridles are passed between modules. With bridle lines connected to extended alignment pins, the tugs use opposing thrust to establish and maintain a reasonable level of pretension between bridle legs as shown in Figure 3, thus preventing snap loads. All the while, the winch draws the marriage bridle legs slowly until the alignment pins are led into the receivers. At close quarter, these pins assist in aligning the module ends and substantially reduce differential motions between the two. Further retraction of the bridle legs reduces the gap, and the stab pins are likely to bear against the face of the adjoining module if they do not find their respective matching receivers straight away. When entry is delayed, the spring-loaded pins function as bumpers to protect the modules, and small random excursions around the receivers continue until each stab pin finds its mark and glides in. Because this technique does not require the precise alignment of all connecting members simultaneously, it has a much better chance of working in the open seaways.

PERFORMANCE TEST

The performance of the recommended connection concept was demonstrated during a follow-on series of seakeeping tests at the Offshore Model Basin located at Escondido, California. These tests were conducted to: (1) observe the dynamic performance of the connection system, particularly the coordination among stabbing pins, alignment pins, and marriage bridles, as well as the fendering function of the stabbing pins, (2) quantify the motional dynamics of the pontoon couple and the associated coupling forces at various stages of the connection process, (3) investigate the influence of pretensioning on the motional dynamics, (4) quantify operational weather window, and (5) investigate manufacturing tolerance requirements. This paper addresses the first three areas.

Test Layouts

The test basin was about 90 m long, 15 m wide and 5 m deep. The test layout was similar to that used previously in 1:8 scale model tests (Huang 1995), with a few revisions to accommodate the larger scale models in the same basin. The U. S. Navy's high sea state pontoons as described by Kane (1996) were again selected as the test bed. Six 1:4 scale models of these pontoons were constructed from plywood and fiberglass. The model alignment pins were constructed roughly 50% as stiff as those used in 1995 experiment to check that characteristic on overall performance. Because the mobility and compatibility of moving parts in the rigid connector assembly are important to the performance of the entire connection system, these assemblies were built precisely to quarter scale using mild steel (A36) to evaluate the efficiency of mechanisms in use. An electric winch mounted on the leading pontoon (near the wave generator) served the function of the warping tug. The general layout of the test setup is shown in Figure 4. Mating pontoons were placed under a mooring ring truss, near the center of the towing tank, at an initial separation of 1.5 m. Wire ropes payed from the electric winch were guided by a pulley through vacant receivers, passed over the water between sections, and attached to the ends of extended alignment pins on the trailing section. The trailing barge that had been intended to represent one of the supporting tugs used in previous tests was eliminated. Two spring-loaded mooring lines were hooked fore and aft to the outside ends of the adjoining pontoons as shown in Figure 4, in order to model the separation force that would be imposed by the sea anchors. The array was pretensioned to about 140, 350, 700, and 1040 N scale force (i.e. 9, 22, 45, and 67 KN pretension in full scale) with a free hanging dead weight attached to the end of the trailing mooring line strung through a series of pulleys. Each pontoon was attached to a motion sensing transducer (MST) that hung from the mooring ring truss.

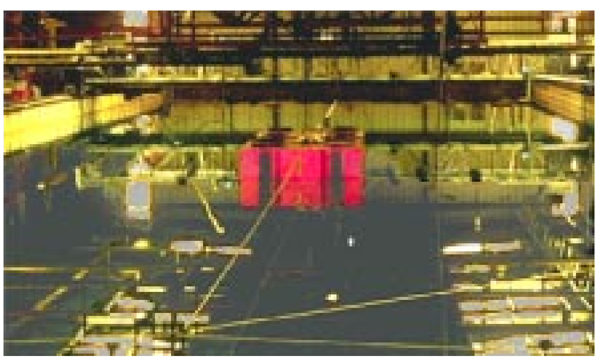


Figure 4. General layout of the test setup.

Tests were conducted in calm water as well as in regular waves of scaled height 1.2 m (4 ft) with periods varying from 4 to 8 seconds, and also in irregular waves representative of sea states 3 and 4. The models were set up initially for tests in head seas. Additional tests were conducted at 15 degrees of head seas for selected cases. The connection process was modeled to resemble an actual operational scenario. Data were collected electronically and the tests were video taped.

Data Acquisition

Motions of individual pontoons were measured in six degrees of freedom using a separate MST for each mating structure. The distance between sections was measured by a rotary potentiometer connected by a string to provide a direct verification of the results observed by the MSTs. Tensions in bridle legs and pretension lines were measured by load cells. The instrumented stab pins measured shear, bending, and tensile loads. Unfortunately, the strain gauges did not function as designed and reported very little useable data. Wave conditions were recorded using two gauges located up stream along the center line of the model assembly and 5 m off the abeam with the mid-point between two pontoons. Time histories of pontoon motion, line tension, and incoming wave posture were recorded on a PC-based computer system. The motions measured by the MST were uncoupled with respect to the center of gravity (CG) of each model situation.

Data Analysis

The connection procedures, dynamic behavior of pontoons, and performance of the connector components are documented on a video tape (Huang 1996b**).** Figures 5 and 6 illustrate the raw data recorded from a typical test run. This particular test was conducted with two pontoons end connected in 5-second head seas of 1.2 meter waves with a 22.2 KN separation force (Figure 7). Figure 5 illustrates the time histories of line tension compared to separation distance. The connection is completed when the separation distance between the adjoining faces is reduced to nothing. As noted, the pretension remains essentially constant over the entire duration, while the tension loads recorded on the marriage bridles and mooring lines oscillate under wave actions. The high tensions in the bridle result from continued winching after the pontoons were pressing against one another in this test case, rather than from the occurrence of snap loads. Figure 6 verifies the active motion of pontoons in an elevated sea state. However, the primary concern to the connector design is the differential displacements at the connector interface rather than the behavior of individual pontoons. These relative motions may be derived from the motions of individual rigid bodies. The results of relative motions in surge, sway, heave, and pitch modes are illustrated in Figures 8, 9, 10 and 11. The joint distributions of relative kinematics that are directly associated to the coupling loads and critical to the structural layout of the connection system have been calculated. Figure 12 is a scatter diagram of velocity versus acceleration in relative surge at various stages of connection process. A completed set of these test results is documented by Huang (1997).

The charts on the next pages are presented in customary English units. Table 1 provides the conversion factors to obtain the same in SI system units.

Table 1. Unit conversions table.

Unit Conversions for	use in the following	Charts
multiply	by	to obtain
kips	4.4482	Kilonewtons
feet	.3048	Meters

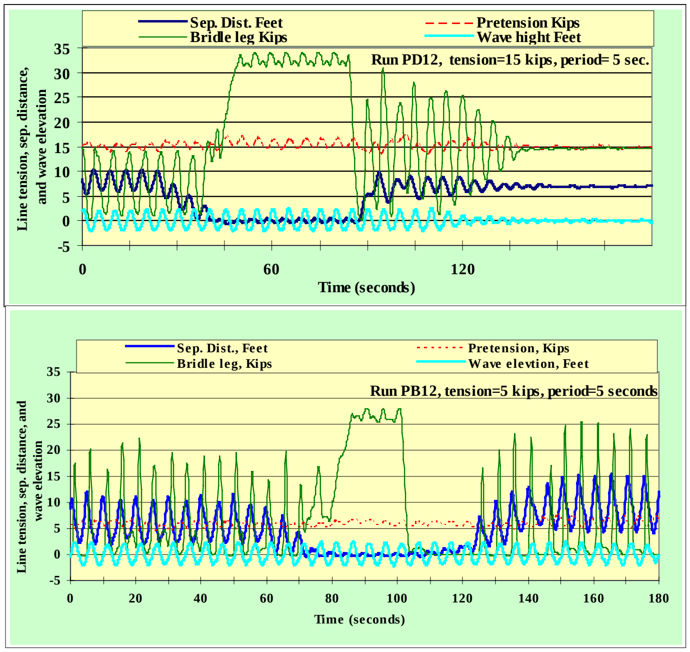


Figure 5. Time histories of line tension with separation distance**.**

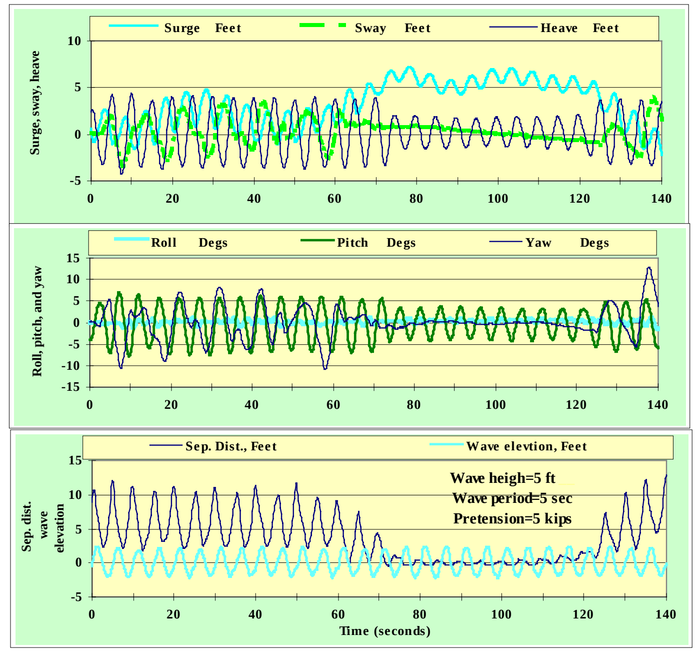


Figure 6. Time histories of a pontoon motion in an elevated sea state

Figure 8. Relative surge motion.

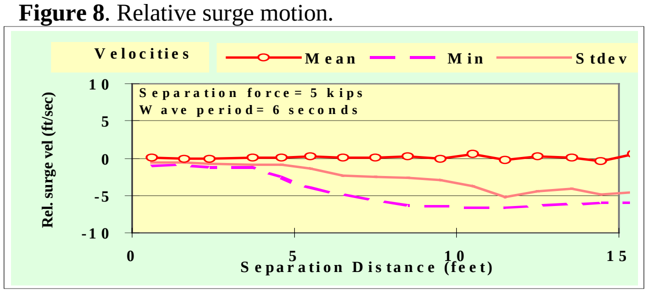
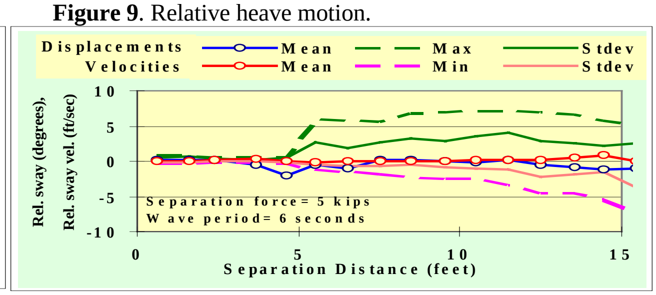


Figure 9. Relative heave motion.



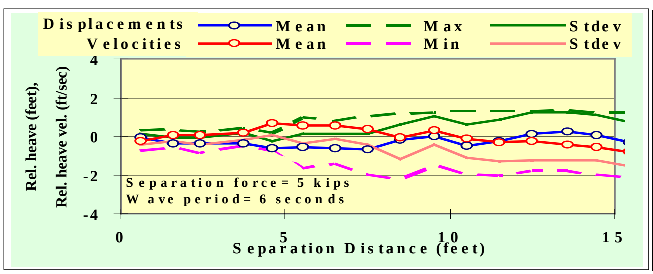


Figure 10. Relative pitch motion.

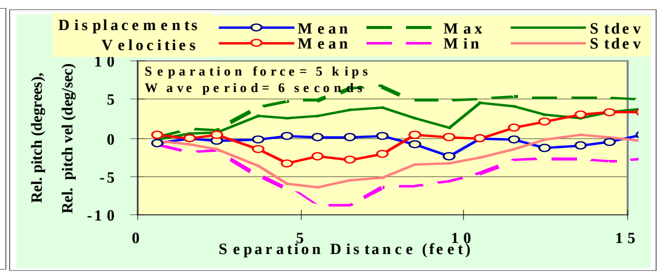


Figure 11. Relative yaw motion.

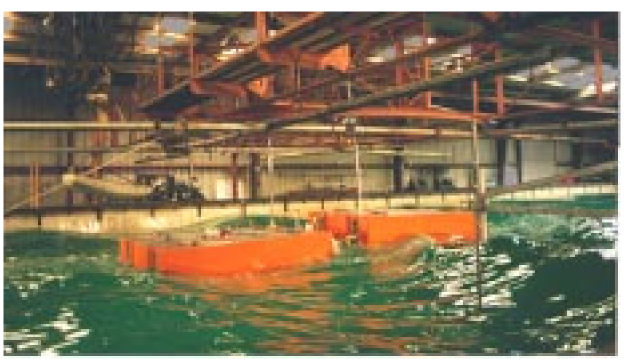


Figure 7. Two pontoons end connected in 5-second head seas.

DISCUSSION

The results of advanced model tests give support to the notion that pontoon modules configured for transport aboard containerships and assembly at sea are very responsive to prevailing sea state. This observation is perhaps the greatest technical challenge assembly on the water. Interface hardware used to complete the initial connection requires a combination of flexibility, strength, and shock absorbing capability to accommodate the large relative motions between pontoons. The progressive connection procedures proposed by the Navy offer ample opportunity for implementing these essential features that ease the transitional impact of drawing together and aligning pontoons for connection. Model tests confirmed that the most

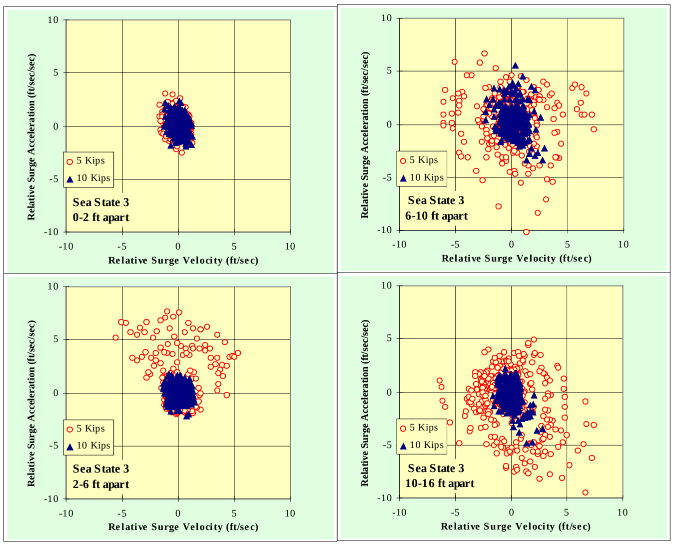


Figure 12. Scatter diagram of relative velocity versus relative acceleration.

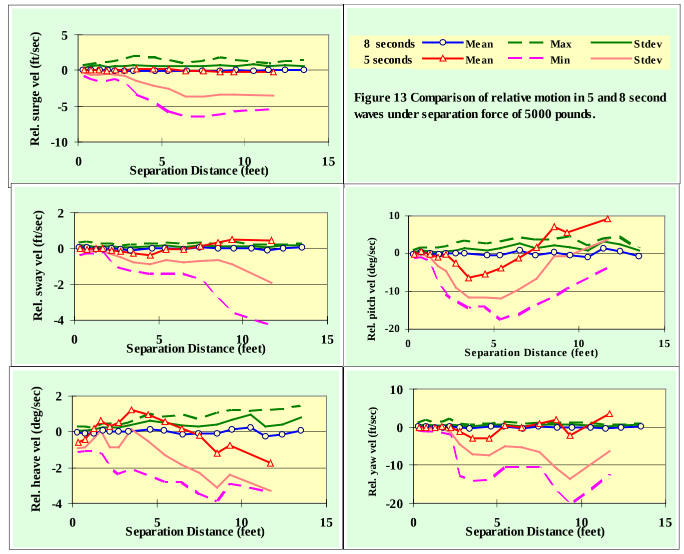


Figure 13. Comparison of relative motion in 5- and 8-second waves under separation force of 5,000 lbs.

significant parameters influencing pontoon behavior during at-sea connections are wave frequency and the pretension force. Individual pontoons are as expected dependent on wave frequency. Relative motions at the interface of two pontoons are even more complicated because of phase differences which are even more sensitive to the wave frequency. Surge motion, in particular, is of most concern during the connection process. Excessive surge causes pontoon collisions and engages mechanical couplings of interface hardware. The subsequent asymmetric coupling forces further excite undesired lateral movements (sway, roll, and yaw) which could otherwise be minimized by taking the pontoon array into the oncoming waves. Figure 13 compares the pontoon motions in 5- and 8-second head waves, respectively, for pontoons that are separated by 1.5 m and witnessing 22.2 KN pretension. In this figure, the results of an 8-second test run were plotted on the positive side, while the results of the 5- second run were plotted on the negative side. The difference in behavior between 5- and 8-second head waves is dramatic enough to impact the strategy of hardware design and development of operational procedures.

This study further confirms the importance of pretension in controlling pontoon motions at the stage of initial connection. Surge motion could be effectively reduced by maintaining an appropriate separation force in the pontoon array to offset the forces of wave-induced surge. These separation forces may be realistically applied by sea anchors or tugs. Because wave-induced surge forces are highly frequency dependent, so is the required pretension to offset these forces. This relationship was clearly demonstrated in a series of tests with separation forces that varied between 9 and 90 KN. As noted in Figure 14, the significant surge that appears when pretension is 22 KN is reduced almost entirely when the pretension increases to 66 KN. At the same time, a substantial change in tension load imposed on the bridle legs as the pretension level is increased can be seen in Figure 15. At only 22 KN pretension, the bridle legs alternate between slack and taut, thus experiencing sharp shock loads. These shock loads, however, do not appear at 66 KN pretension, and the pontoons are drawn together without noticeable signs of inline oscillations. Although the tensions on the bridle legs are of comparable magnitudes to those occurring at 22 KN pretension, they appear almost static. The important implication is that pontoons may be drawn in at any time during the wave cycle without concern of the line snapping.

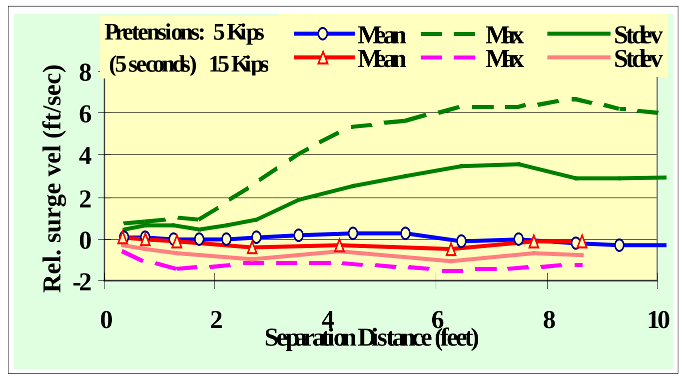


Figure 14. Comparison of relative surge velocities under separation forces of 5,000 and 15,000 lbs, wave height 4 ft, wave period 5 secs.

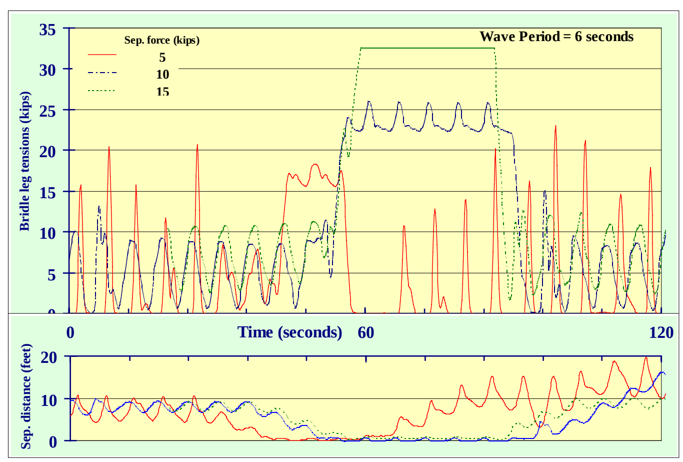


Figure 15. Influence of the separation force on bridle tension loads.

Figure 16 summarizes the pretension requirement, in which the horizontal axis indicates the wave frequency when the bridle legs begin to show signs of slacking at the pretension level indicated by the vertical axis. With the practical range of wind-generated seas, a higher pretension is required to maintain the connection process under control in seaways with shorter prevailing wave periods.

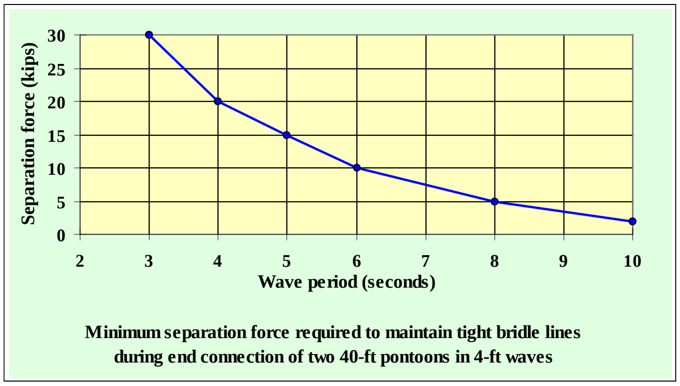


Figure 16. Minimum separation force required to maintain tight bridle lines during end connection of 12.2-m pontoons in 1.2-m waves.

CONCLUSIONS

Hydraulic model tests conducted by NFESC during the past year have demonstrated dramatically the feasibility of assembling large floating platforms on the open seas using prefabricated modules configured for rapid ocean transport aboard commercial containerships. At-sea assembly can be done even in rough water conditions using an approach in which connections between modules are completed progressively. The particular features required in such a progressive system include mechanisms for drawing and aligning modules, fenders to prevent collision damage at close quarters, and hardware strong enough to withstand wave induced loads. Experimental evidence suggests that a practical coupling device for at-sea assembly requires an appropriate combination of flexibility, strength, and shock load absorbing capability to survive the coupling forces resulting from large relative motion between modules. The effectiveness of the proposed at-sea assembly method was demonstrated using quarter scale models. Functional performance of all critically required mechanisms was confirmed for wave conditions exceeding sea state 3.

The greatest technical challenge to the design of coupling devices is the rapid, random motion between adjoining modules. The relative translational motions witnessed at the interface between two 12-m modules mating in sea state 3 conditions could exceed the amplitude of ambient waves. Effective control of relative motion, especially relative surge, is very important to the entire assembly procedure, as concluded from the test results. Assembly is easily and safely done by maintaining an adequate separation force within the pontoon array to offset surge forces generated by wave action. Although connections may be completed at lower magnitudes of separation force, this option comes at the expense of added weight and increased manufacturing costs as stronger, more durable components are needed. In addition, lower separation forces necessitate careful timing and, thus, greater experience on the part of the operating crew.

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